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USING EXPERIMENTAL DESIGN MODULES FOR PROCESS CHARACTERIZATION IN MANUFACTURING/MATERIALS PROCESSES LABORATORIES

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Abstract: Modules dealing with statistical experimental design(SED), process modelling and improvement, and response surface methods have been developed and tested in two laboratory courses. One course was a manufacturing processes course in Mechanical Engineering and the other course was a materials processing course in Materials Science and Engineering. Each module is used as an 'experiment' in the course with the intent that subsequent course experiments will use SED methods for analysis and interpretation of data. Evaluation of the modules' effectiveness has been done by both survey questionnaires and inclusion of the module methodology in course examination questions. Results of the evaluation have been very positive. Those evaluation results and details of the modules' content and implementation are presented. The modules represent an important component for updating laboratory instruction and to provide training in quality for improved engineering practice.

Introduction (history): What follows is a brief discussion of the history of the development of the SED and related topics modules in ME310 and MS&E370. The actual ME310 module on SED is then presented in its format as one lab experiment followed by an example of the SED applications from one of five subsequent experiments which rely on the module for data analysis. A discussion of the comparison of the ME310 and MS&E370 modules is given next. Finally, the results of the evaluation of the effectiveness of the ME310 and MS&E370 modules are presented which are based on measurements of student skills (ME310) and student opinion surveys (ME310 and MS&E370).

ME310 Lab: The ME310 course (Manufacturing Processes I) has been a requirement in the ME curriculum for decades. Industrial Engineering students also may take the course as an option and many usually do so. It is a three credit per semester course with the course grading scheme effectively making for a division of student effort into two-thirds lecture and one-third lab. The labs in the current version of the course are very practice oriented with emphasis placed on principles and practices of machining operations and deformation processing, e.g., extrusion and sheetmetal forming. The SED module occupies one lab period near the beginning of the course.

ME310 Lecture: Although the focus of the module development and applications has been the ME310 laboratory the lecture portion has also been a source of information on SED methods and related quality improvement tools. During 1991-92, for example, Visiting Professor John Corbett used the lecture to introduce quality function deployment (QFD) as a component of the broader topic, "design for competitive manufacturing". In 1992-93, one of the authors (JAC) added presentations on fractional factorial designs, Taguchi methods, and exploratory data analysis tools (check sheets, cause-and-effect diagrams, flow charts, etc.) to the lectures.

MS&E370 Lecture: The module for this course was developed in 1992-93 with the intent of being more comprehensive than the ME310 SED module. The reason for the change of focus and format was two-fold: (1) MS&E370 was undergoing revision and the applications of SED in the course's laboratories would be undertaken as a second stage of the course revision; (2) unlike students in ME310 those in MS&E370 would not likely have completed an introductory statistics or quality engineering course prior to the 370 course.

Historically, the course MS&E370 (Materials Processing-Unit Operations) has been a four credit per semester course with division of effort making the lab count effectively as one credit. In the 1992-93 academic year the course was being revised to make it fit, as an approved option, into the Mechanical Engineering curriculum. Thus, there was an increased interest to incorporate topics such as SED and process characterization and improvement tools in the revision of MS&E370 arose to make it similar to ME310.

Lab Module(s): The actual ME310 Lab module on Statistical Experimental Design is given in Appendix I. Also in that Appendix is an SED Project exercise which is the basis of the student reports for the SED lab session. Subsequent to the SED lab session there are five (5) SED-based lab sessions: Extrusion, and Forces and Power in Metal Cutting I and II (drilling; grinding; milling; turning). The five applications of SED along with the SED module itself comprise approximately 40%, or 110 points out of 250, of the value allocated to ME310 Lab reports. A copy of the ME310 Lab data sheet used in the SED application for the Extrusion experiment is included in Appendix I. That data sheet is typical of the forms used in the five SED applications labs.

The module on Process Characterization Tools prepared for MS&E370 is excerpted in Appendix II. Shown there are: (i) the cover page for the module which outlines the module's intent, and (ii) a summary figure from the module, "PROCESS IMPROVEMENT TOOL BOX". As the cover page "Abstract" indicates the MS&E370 module covers a wider range of topics than the ME310 SED module. Its future application in the revised MS&E370 was the basis for such a range of topics being introduced. An exercise was included in the MS&E370 module which is similar to the 2^3 design analysis of the ME310 SED module. However, in the first semester of its use none of the other lab experiments in MS&E370, e.g., casting, heat treating and joining, were modified to take advantage of the new process characterization/improvement module.

Evaluation of Effectiveness: Two methods of evaluation were used to determine the effectiveness of the ME310 module on SED. These methods were: (1) evaluation of each student's skill level in designing, analyzing and interpreting a standard 2^3 factorial experiment during an exam; (2) surveying each student to gain information about their attitudes towards the perceived general usefulness and possible future career applications of SED methods. Only the survey method was used with the students in MS&E370 since they did not have the opportunities for practice of the skills afforded in ME310.

Skill Level - ME310: As a part of one of the ME310 lecture examinations a problem was given which asked the students to compare their actual lab experiment on sheetmetal forming (done in sequence prior to their SED lab, and also done without regard to balancing the pattern of investigation of the three test factors of: alloy type, sheet thickness and lubrication) to data from a standard 2^3 factorial design of the same experiment. Of the sixty-five (65) students taking the exam 62 got the problem completely correct, except for some math errors in calculating the predictive model residuals. The three remaining students' error was in writing the standard design in reverse order, after which the rest of their calculations were correct except for the wrong signs in the calculations of the predictive models. The exam was closed book and closed notes. They, as a group, had clearly developed the skill of being able to design and analyze simple factorial designs. Of equal importance, they were able to recognize the "bad" design of the original sheetmetal forming experiment.

Attitudes Survey - ME310 and MS&E370: At the end of Spring Semester 1993 the 65 students in ME310 and 6 in MS&E370 were surveyed to determine how effective they felt SED was as an experimental tool. The summary results from three questions relating to usefulness of SED are presented below. The percentages are based on the total number of responses who either ***agree***, or ***strongly agree*** with the statement.

Statement	ME310	MS&E370
I would recommend that SED methods be incorporated in all lab courses.	82.5%	66.7%
I think SED is a tool that I will find useful in future applications.	95.2%	100%
I would like to gain more experience in SED methods	88.9%	83.3%

The survey results provide a strong signal for those of us developing laboratory courses and experiments. It is worth adding at this point that several students in both courses were co-op students. Their comments on the surveys were that they had already been introduced to these experimental planning and analysis tools during their co-op. Unfortunately, except for these instances (ME310 and MS&E370) they were not being given regular access to such modern laboratory analysis methods in their engineering education. (We should note here that the University of Wisconsin - Madison's Plasma Processing Laboratory offers SED instruction as part of the plasma lab course at the graduate level. An SED module was written by Prof. Soren Bisgaard for that course.)

Summary: We have outlined an example of an instructional plan for incorporating statistical experimental design methods into existing laboratory courses. The incorporation of these techniques has been shown to be effectively accomplished in terms of both student skill development and attitudes regarding experimentation. Furthermore, this procedure of making the SED topic an integral part of the overall lab operation strengthens the entire course with minimal effect on the curricular focus of the lab course.

Instructor Notes: The major impediment to using SED methods in existing laboratory courses is lack of instructor familiarity with the concepts. We offer two recommendations for overcoming that barrier. The first suggestion is to enlist the aid of a colleague at your institution who has a background in statistical methods to help you write your own module(s) using this module as a guide. In this approach you will find a willing support person with statistics as a background and you will 'learn by doing' as you develop the module to fit your specific circumstances. A second way to modify your course(s) to include the SED techniques is to attend formal workshops or short courses offered by a variety of organizations. We will not list any of those offerings here, but can provide you with suggestions if you contact us.

Acknowledgements: There have been many individuals responsible for the successful development of the ME310 SED modules. Particular mention should be made of the Teaching Assistants who have taught the lab course and specifically contributed to the lab's success. They are, in alphabetical order: John Bashel, Dan Bee, Dave De Haan, Bill Durkin, Pat Galecki, Bob Gustafson, Jim Rink, Russ Tilsner, Dave Van Zuest, and Jim Witte. The encouragement of several faculty also was essential to implementing these changes. The faculty to be acknowledged include, in alphabetical order: Prof. Soren Bisgaard (IE and Associate Director of the Center for Quality and Productivity Improvement), Prof. Marvin DeVries (Chairman of ME and a long time proponent of use of SED in manufacturing processes), and Prof. Slawomir Spiewak (ME and faculty in charge of ME310 during these changes). Two of the authors (BA and JC) also wish to recognize the support to CQPI by a grant from the Alfred P. Sloan Foundation during 1992-93 when this report was prepared.

(*Appendix I*)

ME310 Lab
STATISTICAL EXPERIMENTAL DESIGN

Key Words: Statistical Experimental Design; Factorial designs; Randomization; Interaction Effects; Predictive models; Process characterization; Continuous Improvement; Response surfaces; Exploratory data analysis.

Prerequisite Knowledge: You are expected to have taken an introductory materials science/engineering course and math through differential equations. No prior course work in statistics is required.

Purpose and Learning Objectives: The *Purpose* of this instructional module is to introduce you to an effective method of planning, conducting, analyzing and interpreting experiments. This module will be followed by a series of laboratory modules where practice of the methods will help to develop skills The methodology of statistical experimental design (SED) is especially useful for the initial characterization and continuous improvement of processes, particularly industrial processes.

Learning Objectives After completion of this module you should have accomplished the following *knowledge*, *skill* and *attitude* objectives:

Knowledge Objectives Know about the use of: *Factorial SED techniques and their capability to determine the effects of major process control parameters and interactions between parameters; randomization,replication, blocking, and confounding in conducting and analyzing experiments; Exploratory data analysis tools;*

Skill Objectives Be able to: *Plan, and properly conduct a full 2^n factorial design; Calculate contrasts and effects from standard results; Determine significant effects; Construct empirical predictive model of behavior based on significant effects; Construct contour diagram (preliminary response surface) from predictive behavior model; To aid in problem solving: Construct check sheets, Pareto diagrams, histograms, flow charts, cause-and-effect diagrams, scatter diagrams for a given data set;*

Attitude Objectives *Actively promote the application of: Designed experiments in the determination of major process effects for quality improvement and optimization; Simple graphical methods of data analysis;*

Equipment and Supplies: The SED modules require only data from real experiments or industrial operations. Access to a computer software package with capability to do graphics manipulations such as cube plots, normal probability plots, flow chart construction, etc. is desirable. Such software is best presented as a demonstration (needing appropriate hardware for overhead projection from computer screen) initially with subsequent student access to the software for report calculations.

Introduction to Statistical Experimental Design

Statistical Experimental Design is a method of experimentation which provides the experimenter with tools to accurately and efficiently collect and analyze data. *A factorial experiment* usually involves several factors which are varied by the experimenter and one or more responses which are to be optimized. In the past, engineers and scientists have relied on one-factor-at-a-time experiments. These are experiments in which each factor in the experiment is varied independently while the other factors are kept constant. However, this type of experimentation has been found to be inadequate to produce the speed and accuracy needed to develop new products and processes. The most notable short coming of the one-factor-at-a-time approach is that the interaction that factors often have with each other cannot be estimated. For example, in a sheetmetal forming operation, it may be found that at one thickness of material, lubrication has a large effect on the formability of the material, but at another thickness level the lubrication has almost no effect. A one-factor-at-a-time experiment will not provide any information about this interaction. However, a factorial experiment based on modern, statistical principles of experimental design will be able to detect such interaction effects.

Two-Level Factorials

Although there are many types of statistically designed experiments, some of the most useful are called two level factorials. For a two level factorial design each factor is set at a high and low level (usually a small amount above and below what is currently considered the best setting of that factor). Each possible combination of settings of the factors is then run. Due to the properties of the experiment, the experimenter can determine which factors have the most effect on the response, which factors interact, and build an approximate model relating the factors to the response. This information can then be used to optimize the response. Unreplicated two-level, three factor experiments, called 2^3 factorials, are especially useful for efficiently investigating a process about which very little is known. These experiments only require 2^3 or 8 experimental trial runs and the results can be used to get ideas about the underlying relationships of the factors with the response during the exploratory phase of an investigation. To confirm these results for publication or other such purposes, replications would be needed.

As an example, a 2^3 factorial mill experiment will be designed and analyzed. The three factors will be the Speed of the cutter (RPM), the Feed rate (in./min.), and the Depth Of Cut or D.O.C. (in.).

Coding of the Factor Levels

For ease of analysis, it is convenient to code the factors into high and low levels as follows:

Factor	Low Level (−1)	High Level (+1)	Units
Speed (S)	50	75	RPM
Feed (F)	2.5	3.5	in./min
D.O.C. (D)	.1	.2	in.

Using the codes "–1" and "+1" all the possible combinations of levels must now be listed. For simplicity we will use "–" to show the "–1" level and "+" to show the "+1" level. The order listed below is called the standard order and you can quickly see that the pattern of the standard order makes it easy to detect whether all 2^3 possible combinations of low and high factor levels are present.

Standard Order	S	F	D
1	–	–	–
2	+	–	–
3	–	+	–
4	+	+	–
5	–	–	+
6	+	–	+
7	–	+	+
8	+	+	+

Randomization

It is unwise to run the actual experiment in the standard order. For example, if the experiment were run in standard order and the calibration or any other uncontrolled factor changed halfway through the experiment, it would be impossible to tell the difference between the effect of the uncontrolled change and the effect of depth of cut (D) since this factor changes only once at the midpoint of the experiment. This leads to the idea of Randomization. *Randomization* is a principle which states that if the experimental trials are run in random order, it is very unlikely that any uncontrolled factor change will exactly correspond to any of the controlled factor changes and therefore the effect of the uncontrolled factors should not significantly bias the experimental results. For this reason, the trials in this experiment will be run in a random order. To determine the random order, the numbers 1 through 8 should be written on small pieces of paper and drawn from a hat or a bowl.

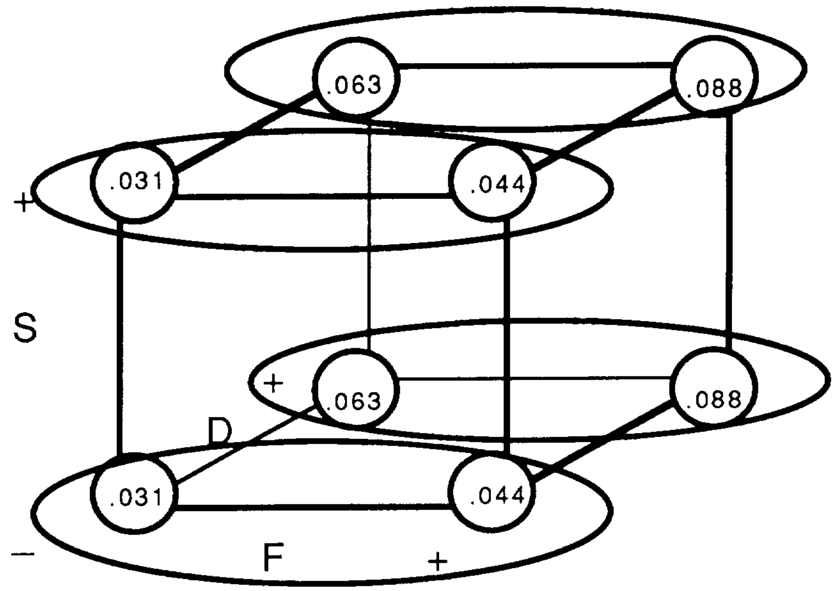
Cube Plots

A *cube plot* is a method of plotting the data from a 2^3 factorial. The plot consists of a cube with a response value located at each corner. Each dimension of the cube represents the coded scale of one of the factors from the low level (–) to the high level (+). An example is given below using metal removal rate (Q) of the mill as the response plotted versus the factors; Speed (S), Feed (F), and D.O.C.(D).

This plot is useful because one can easily compare the four responses with low F on the left side of the cube (.031, .031, .063, .063) with those with high F in the corresponding location on the right side of the cube (.044, .044, .088, .088) to see the effect of F on metal removal rate,(Q).

In the figure below you will notice that there are four separate comparisons which can be made and in each comparison the only factor changed is F. These separate comparisons are called *hidden replications* and are the reason that, even when unreplicated, 2^3 factorials can be relied upon to convey a great deal of information. Similarly one can compare the front and back of the cube to see the effect of D on Q or the top and bottom of the cube to see the effect of S on Q. In the cube shown, one can see that the responses on the top of the cube are identical to those in the corresponding position on the bottom of the cube, which shows that Speed has no effect on Q. This confirms the already known relationship, Q = (D.O.C.)*(Feed)*(Width of Cut), in which Speed is not a factor.

Metal Removal Rate of the Mill



Calculation and Meaning of the Effects

To this point, the effect of each factor has been spoken of in a qualitative way. However, the specific quantitative definition of the *main effect* of a given factor on a given response can now be defined as the average difference between the responses at the high level of the factor and the responses at the low level of that factor. Thus, the effect of Feed on Q is the average of the differences (.044 – .031), (.044 – .031), (.088 – .063), and (.088 – .063). Therefore, for the ranges used in this experiment the effect of Feed (F) on Q is .019, the effect of D.O.C. (D) on Q is .038, and the effect of Speed (S) on Q is zero.

The *interaction effect* between two factors is the average amount that the effect of a factor changes when another factor is varied. For example, the effect of F on Q at the low level of D is the average of (.044 – .031) and (.044 – .031) or .013, but at the high level of D the effect of F on Q is .025. The interaction effect then is (.025 – .013)/2 or .006. These interaction effects are most easily calculated using the table shown below, where the interaction effect between Feed (F) and D.O.C.(D) is called FD and the other interaction effects are similarly called SF and SD. SFD is the three way interaction effect. The contrast for each column is the sum of the data when the data is given the signs of that column as shown in the example column for FD. All effects, including the main effects, are calculated as shown by dividing the contrast for each column by 4*. In this case the only interaction effect is the interaction between the Feed and the D.O.C. (FD); all other interactions show values of zero.

	Main Effects			Interaction Effects					
Trial #	S	F	D	SF	SD	FD	(example FD)	SFD	Q
1	–	–	–	+	+	+	(+.031)	–	.031
2	+	–	–	–	–	+	(+.031)	+	.031
3	–	+	–	–	+	–	(–.044)	+	.044
4	+	+	–	+	–	–	(–.044)	–	.044
5	–	–	+	+	–	–	(–.063)	+	.063
6	+	–	+	–	+	–	(–.063)	–	.063
7	–	+	+	–	–	+	(+.088)	–	.088
8	+	+	+	+	+	+	(+.088)	+	.088
Contrast	0	.076	.152	0	0	.024	(.024)	0	
Effects	0	.019	.038	0	0	.006	(.024/4=.006)	0	

*4 equals the number of differences being averaged, and can be easily determined by the number of + and – pairs in the column.

Model Building

Once the important effects have been identified, a model can be created which will estimate the response, in this case Metal Removal Rate, at locations in or on the cube which were not specifically run in the experiment. The model uses the coded scale –1 to +1 for each of the factors and includes only the strong effects. The coefficients for the polynomial model are exactly one half of the effects previously calculated, so the model we will use is:

$$Q = (.0095)F + (.019)D + .0565 \qquad \text{(Model 1)}$$

where .0565 is the average value of the Metal Removal Rate data. If we consider the FD interaction to be important, the model would then be:

$$Q = (.0095)F + (.019)D + (.003)FD + .0565 \qquad \text{(Model 2)}$$

Based on Model 1, we would predict a Q of .07075 for F=.5 and D=.5.
Model 2 would predict a Q of .070825, which shows that the interaction term is indeed quite a small effect. Using the cube plot and the model we can see that if Q is to be increased, Feed and D.O.C. must be increased and Speed has no influence on Q.

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ME 310 Project II

Given the data in the standard order table below, perform the following analysis: (Note: This experiment was performed in random order.)

1. Calculate the contrasts and main effects of speed (S), feed (F), and depth of cut (D). *Note: Show all calculations, no spread sheet analysis is allowed.*
2. Calculate the contrasts and interaction effects of all control factors. *Note: Show all calculations, no spread sheet analysis is allowed.*

	Main Effects			Interaction Effects				
Trial #	S	F	D	SF	SD	FD	SFD	Hpu
1	–	–	–	+	+	+	–	29.5
2	+	–	–	–	–	+	+	40.7
3	–	+	–	–	+	–	+	28.6
4	+	+	–	+	–	–	–	40.2
5	–	–	+	+	–	–	+	21.3
6	+	–	+	–	+	–	–	34.1
7	–	+	+	–	–	+	–	21.6
8	+	+	+	+	+	+	+	34.0
Contrast								
Effects								

3. Draw the cube plot with the appropriate response at the corners of the cube.
4. On your cube plot, circle the four (4) hidden replications of feed (F).
5. Rank effects in ascending order, or lowest to highest, and calculate the cumulative probabilities for each effect given by the equation:

$$P(i) = 100\,(i - .5)\,/\,n$$

where:
i = ascending order number associated with each piece of data.
n = size of the sample or number of effects.

6. Plot the cumulative probabilities on the normal probability plot provided.
7. Determine which main effects and/or interaction effects are significant from the above analysis.
8. Develop the coded model for Hp_u using the significant effects.
9. From the coded equation, determine the actual value for speed if it is desired to maximize depth of cut and have a Hpu value of 30.2. You will need to use the table for coded factors on page 2 of the SED Lab Notes.

NOTE: **For further examples of the graphical methods of using cube plots to analyse factorial designed experiments please refer to the following References. To see how an additional problem is analyzed see the Box and Bisgaard 1988 article in *Mechanical Engineering*. For a more complete, but very readable description of cube plots refer to the textbook by Box, Hunter and Hunter (1978).**

Copies of the ME310 Lab Manual may be requested from Prof. Donald Ermer at the Mechanical Engineering Department, Univ. of Wisconsin-Madison, 1513 University Ave, Madison, WI 53706. New copies will, however, not be printed after Fall Semester 1993

Extrusion Summary Sheet

	S.O. 1*	S.O. 2	S.O. 3	S.O. 4	S.O. 5	S.O. 6	S.O. 7	S.O. 8
Random Order								
Direction	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse
Die Geometry	Square	Square	Round	Round	Square	Square	Round	Round
Lubrication	No	No	No	No	Yes	Yes	Yes	Yes
Break Through Force (lbs)								

SQR= - FWD= - N/L= -
RND= + REV= + LUB= +

* S.O. represents "standard order"

	Main Effects			Interaction Effects				
S.O. #	D	G	L	DG	DL	GL	DGL	B.T. Force
1	−	−	−	+	+	+	−	
2	+	−	−	−	−	+	+	
3	−	+	−	−	+	−	+	
4	+	+	−	+	−	−	−	
5	−	−	+	+	−	−	+	
6	+	−	+	−	+	−	−	
7	−	+	+	−	−	+	−	
8	+	+	+	+	+	+	+	
Contrast								
Effects								

Sheet Metal Forming Experimental Design

	Main Effects			Interaction Effects				
Std. order				Axt	AxL	txL	AxtxL	Bulge
1				+	+	+	–	34.0
2				–	–	+	+	21.3
3				–	+	–	+	34.3
4				+	–	–	–	28.6
5				+	–	–	+	40.2
6				–	+	–	–	21.6
7				–	–	+	–	40.7
8				+	+	+	+	29.5
Contrast								
Effects								

Coding of the Factor Levels

For ease of analysis, it is convenient to code the factors into high and low levels as follows:

Factor	Low Level (−1)	High Level (+1)	Units
Alloy (A)	2024-0	2024-T3	treatment
thickness(t)	0.05	0.125	in.
Lube (L)	No lube	Lube	lubricant

NOTE: This page is from ME310 Exam #2. It is the data sheet for a question about how to reevaluate the Sheet Metal Formability Lab if a statistically designed experiment had been conducted. In addition to completing the data table a cube plot and process model equation was required as part of the exam question.

(Appendix II)

MS & E 370

Process Design and Control Toolbox: I
Exploratory Data Analysis Tools and Statistically Designed Experiments

Key Words: Statistical Experimental Design; Factorial designs; Randomization; Interaction Effects; Predictive models; Process characterization; Continuous Improvement; Response surfaces; Exploratory data analysis.

Prerequisite Knowledge: You are expected to have taken an introductory materials science/engineering course and math through differential equations. No prior course work in statistics is required.

Purpose and Learning Objectives: The *Purpose* of this instructional module is to introduce you to an effective method of planning, conducting, analyzing and interpreting experiments. This module will be followed by a series of laboratory modules where practice of the methods will help to develop skills. The methodology of statistical experimental design (SED) is especially useful for the initial characterization and continuous improvement of processes, particularly industrial processes.

Learning Objectives: After completion of this module you should have accomplished the following *knowledge*, *skill* and *attitude* objectives.

Knowledge Objectives Know about the use of: Factorially Designed experiments; Blocking, confounding and randomization in conducting and analyzing experiments; Exploratory data analysis tools;

Skill Objectives Be able to: Plan, and properly conduct a full 2^n factorial design; Calculate contrasts and effects from standard results; Determine significant effects; Construct empirical predictive model of behavior based on significant effects; Construct contour diagram (preliminary response surface) from predictive behavior model; Construct check sheets, Pareto diagrams, histograms, flow charts, cause-and-effect diagrams, scatter diagrams for a given data set;

Attitude Objectives Promote the application of: Simple graphical methods of data analysis; Using designed experiments in the determination of major process effects for improvement and optimization.

Equipment and Supplies: The SED modules require only data from real experiments or industrial operations. Access to a computer software package with capability to do graphics manipulations such as cube plots, normal probability plots, flow chart construction, etc. is desirable.

Abstract: Traditional methods of designing and improving processes have been based on one-factor-at-a-time (***1-faat***) procedures for obtaining information about the processes. Such methods are known to be inefficient and often misleading with regard to the way process variables are determined to affect the output. In this module we will describe and illustrate the use of a variety of tools, or techniques, which are especially easy to use for exploring existing data, and for obtaining and interpreting new data. The tools which will be introduced are: *flow diagrams; check sheets; Pareto charts; histograms, control charts, cause-and-effect diagrams; designed experiments; response surfaces*. These tools place strong emphasis on visualization of data rather than on numerical descriptions of a system. They can, consequently, be effectively used by a wide range of personnel involved with design and monitoring of processes. Special emphasis will be given to factorial methods of experimental design since those methods provide one of the best techniques for acquiring data and converting it into useful information.

PROCESS IMPROVEMENT TOOL BOX